Energy Dependence of Azimuthal Correlations
(and more)
in Nucleus-Nucleus Collisions at the CERN SPS

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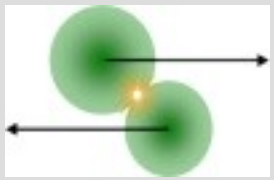


Overview

- Why angular correlations? at the SPS?
- NA49
- Two-particle azimuthal correlations
  - centrality scan (*Pb*+*Pb* at $\sqrt{s_{NN}}$ = 17.3 GeV)
  - p_T^{asc}/p_T^{trg} scan (*Pb*+*Pb* at $\sqrt{s_{NN}}$ = 17.3, 6.3 GeV)
  - system-size scan (*p*+*p*, *Si*+*Si*, *Pb*+*Pb* at $\sqrt{s_{NN}}$ = 17.3 GeV)
  - energy scan (*Pb*+*Pb*, *Au*+*Au* at $\sqrt{s_{NN}}$ = 6.3 – 200 GeV)
  - comparison with UrQMD
- Two-particle $(\Delta\eta,\Delta\phi)$ correlations
- Summary

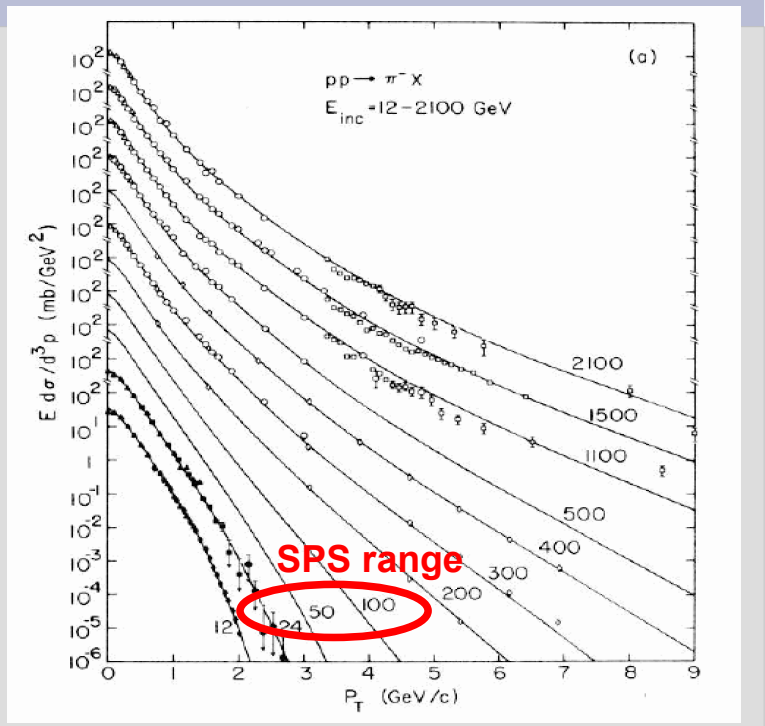
Motivation

- Angular correlations at high p_T
  - can probe jet-medium interactions
  - exciting results from RHIC
  - largely neglected at the SPS

- Complications at the SPS
  - small high-p_T hadron yields
  - transition from soft to hard physics unknown
  - effect of Cronin enhancement unknown, expected to be strong
  - theory: large uncertainties in perturbative-QCD calculations

- What do we really see?

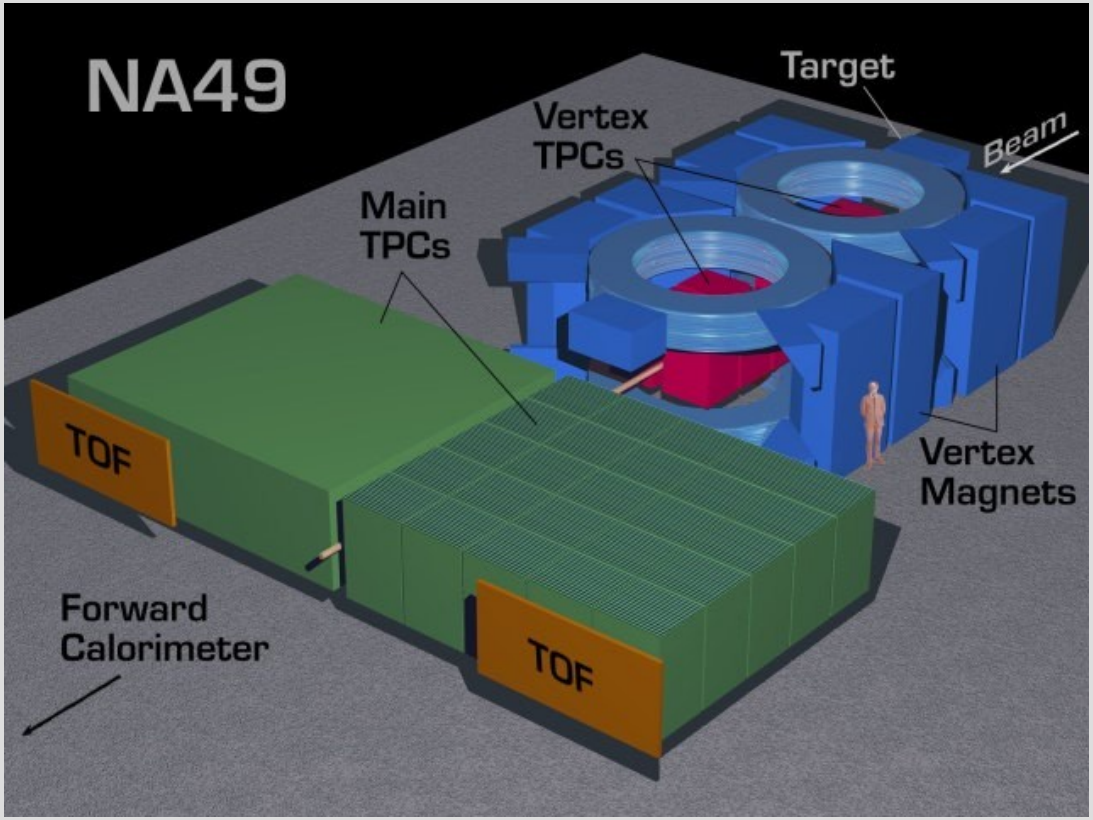
E. W. Beier et al., Phys.Rev.D18:2235,1978



NA49

- Large-acceptance hadronic spectrometer
- Four large-volume TPCs
- Two ToF walls
- Beam/trigger detectors
- Forward Calorimeter – centrality selection
- Momentum resolution:

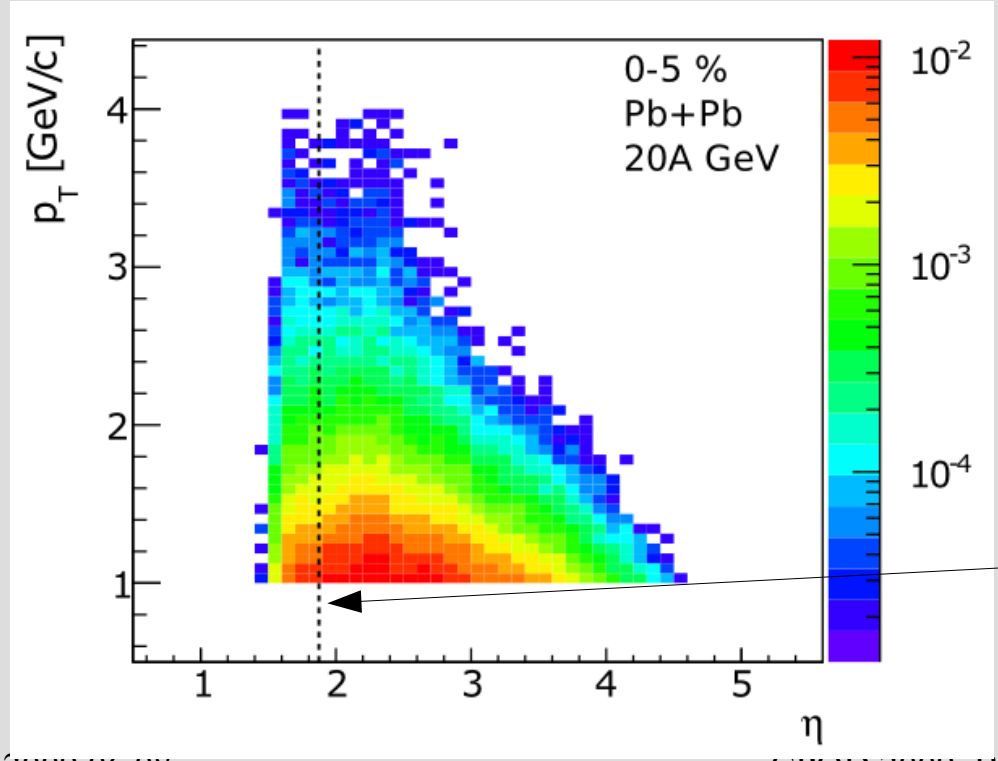
$\sigma(p)/p^2 = (0.3-7)\cdot 10^{-4}$ (GeV/c)$^{-1}$

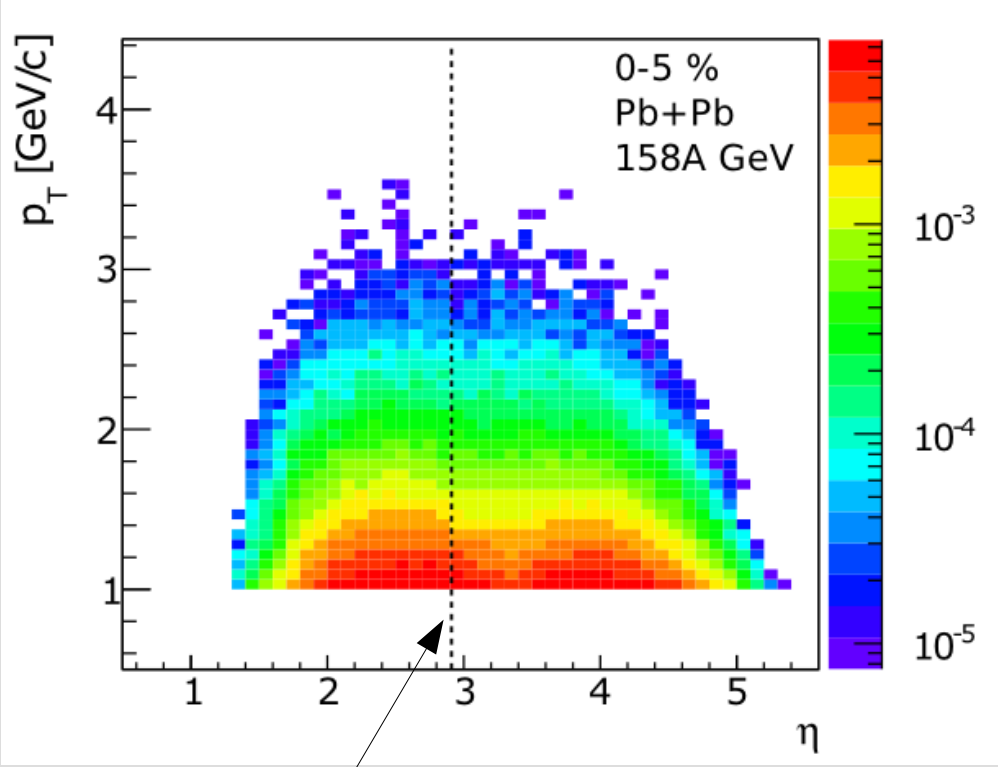


Two-particle Δϕ Correlations

Particle selection:

- η ϵ [1;6]
- p_T^{trg} ϵ [2.5;4.0] GeV/c
- p_T^{asc} ϵ [1.0;2.5] GeV/c
- In each pair, $p_T^{asc} < p_T^{trg}$





$\eta = y_{CM}$

Two-particle $\Delta\phi$ Correlations
Basic Definitions

- Correlation function:

$$C_2(\Delta\phi)=\frac{N_{corr}(\Delta\phi)}{N_{mix}(\Delta\phi)}\frac{\int N_{mix}(\Delta\phi')d(\Delta\phi')}{\int N_{corr}(\Delta\phi')d(\Delta\phi')}$$

$$where$$

$$0\leqslant\Delta\phi\leqslant\pi$$

  - corrected for non-uniform azimuthal acceptance

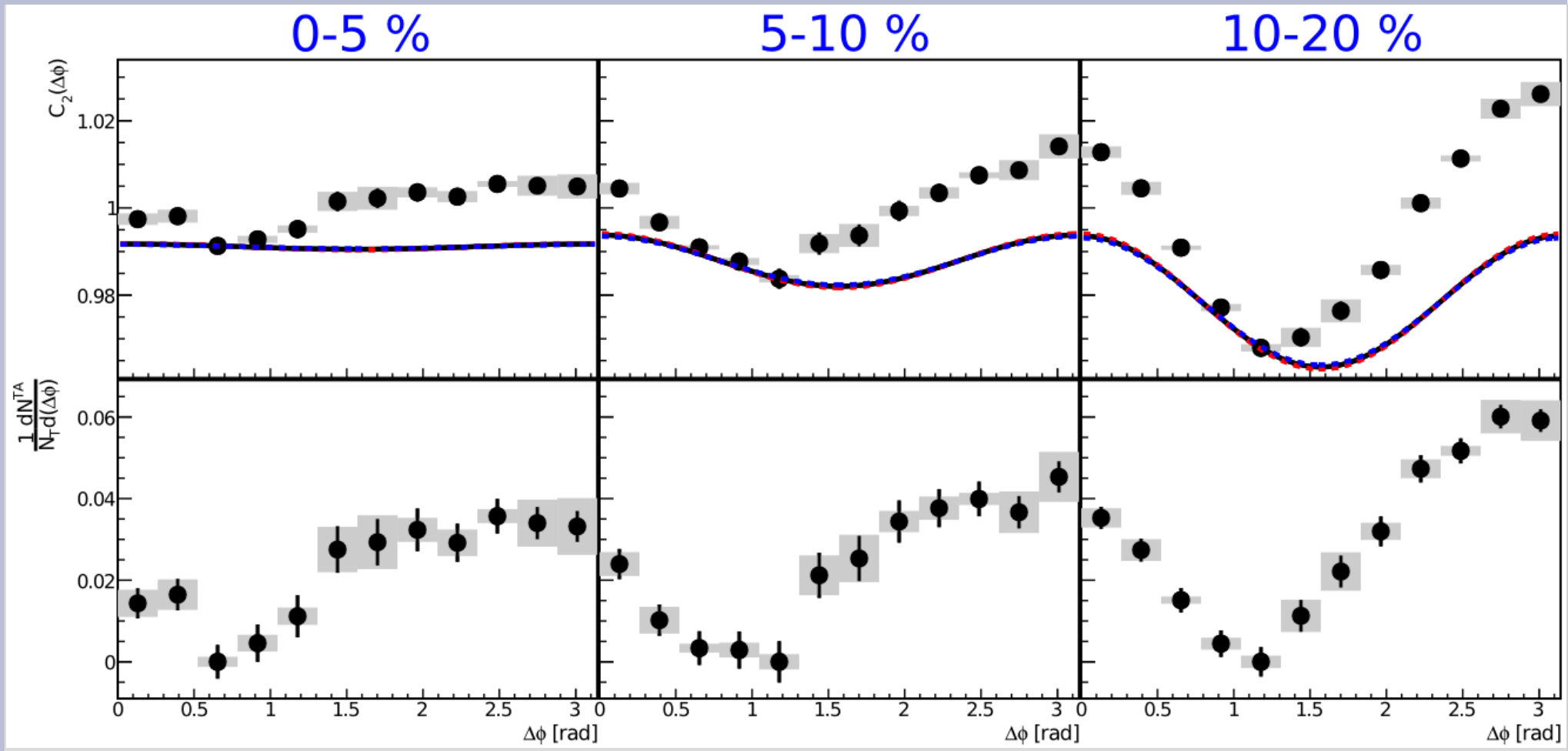
- Flow subtraction: two-source model / ZYAM approach
  - Ajitanand et al., Phys.Rev.C72:011902,2005
  - mostly unused here

- Per-trigger conditional yield:

$$J_2(\Delta\phi)=\frac{1}{N^T}\frac{dN^{TA}_{di-jet}}{d(\Delta\phi)}=\frac{C_2^{jet}(\Delta\phi)}{\int C_2(\Delta\phi')d(\Delta\phi')}\frac{N^{TA}}{N^T}$$

Two-particle Δϕ Correlations

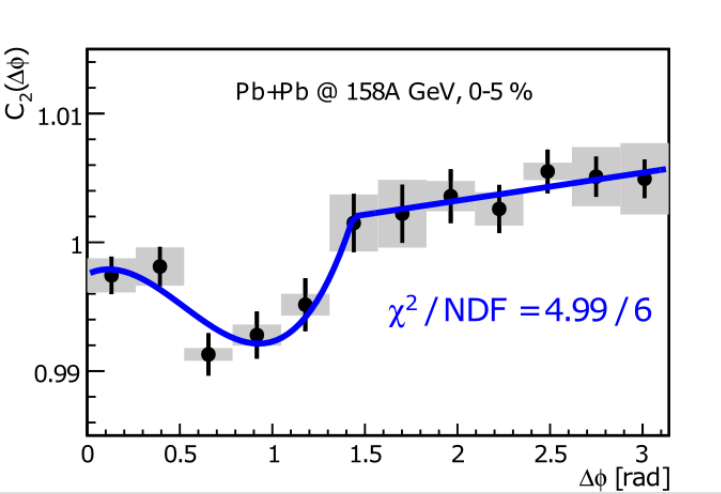
Pb+Pb at 158*A* GeV



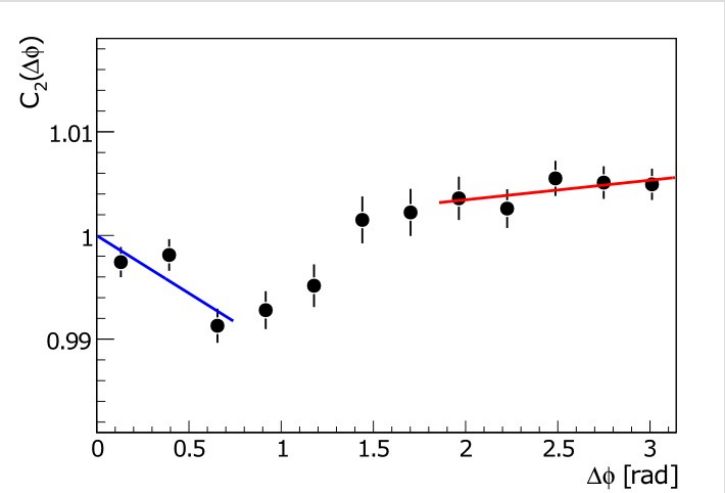
Flattened away side in most central collisions

Two-particle Δϕ Correlations
Auxiliary Techniques

- Polynomial fit
  - more readable comparison plots

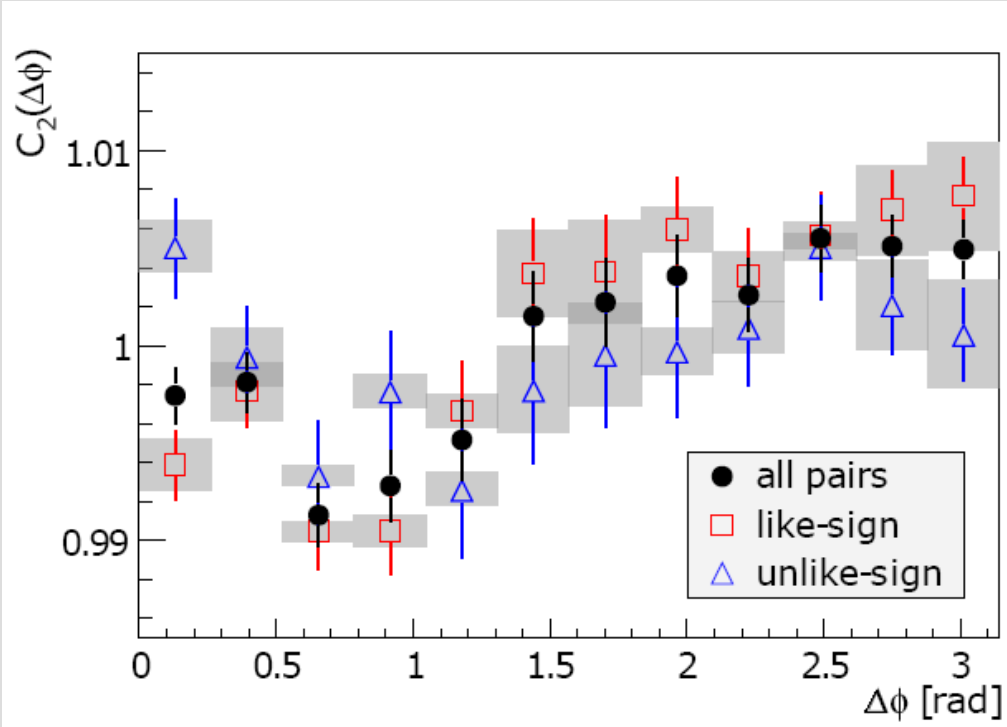


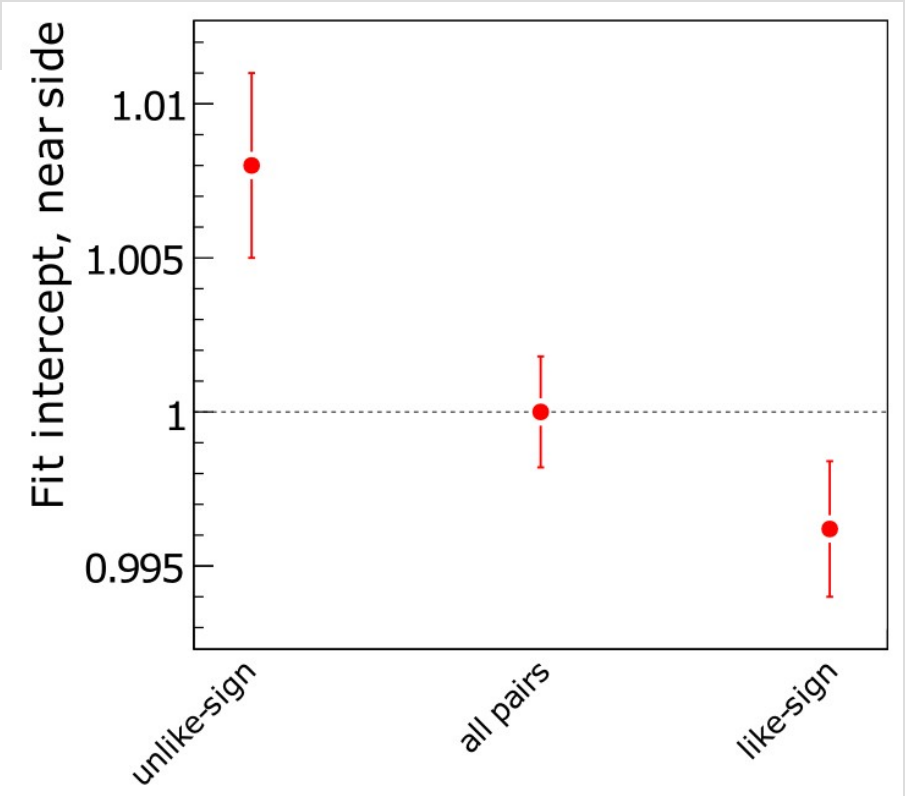
- Linear fits of near and away side
  - quantification to facilitate comparison



Two-particle Δϕ Correlations
Pb+Pb at 158*A* GeV

- Near-side amplitude of $C_2(\Delta\phi)$ depends on charge of triggers and associates



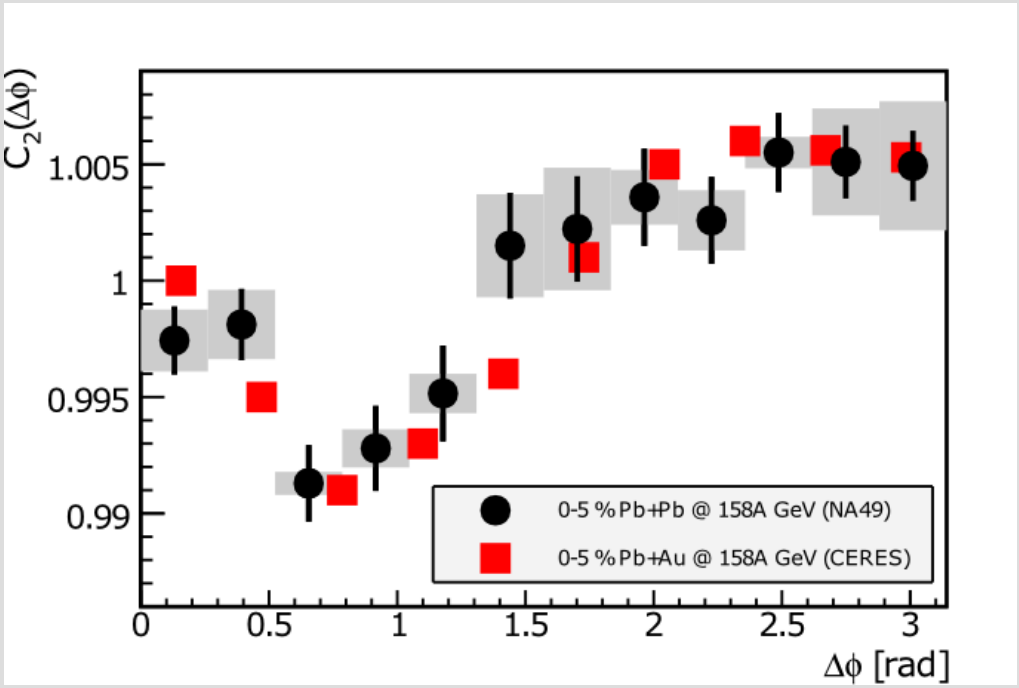


- Difference in like- vs. unlike-sign: charge conservation?

Two-particle Δϕ Correlations
Pb+Pb at 158*A* GeV

Comparison with CERES

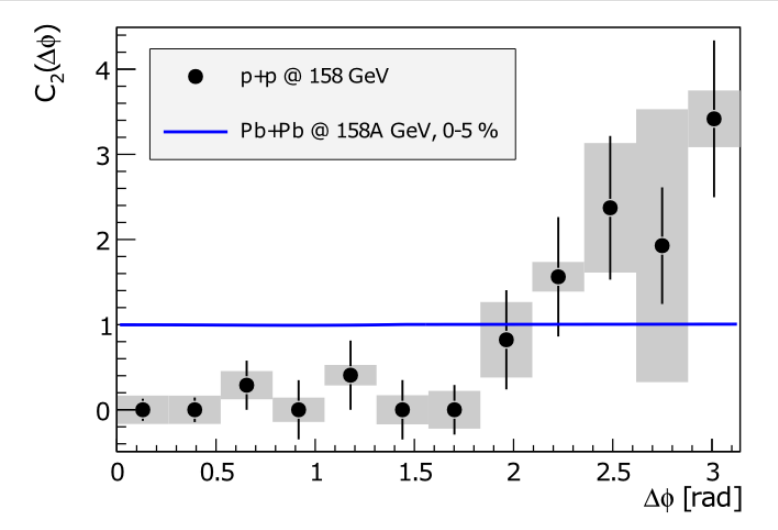
- Full, uniform azimuthal acceptance
- $2.10 < \eta < 2.65$

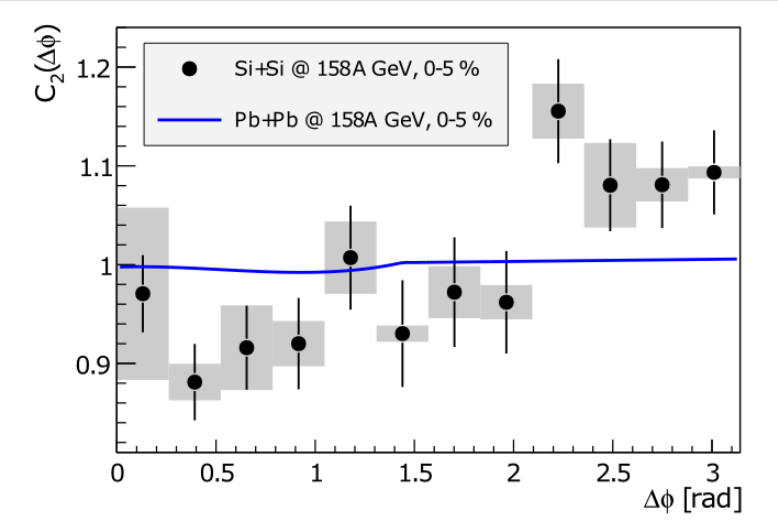


CERES, J.Phys.G34:S697-700,2007

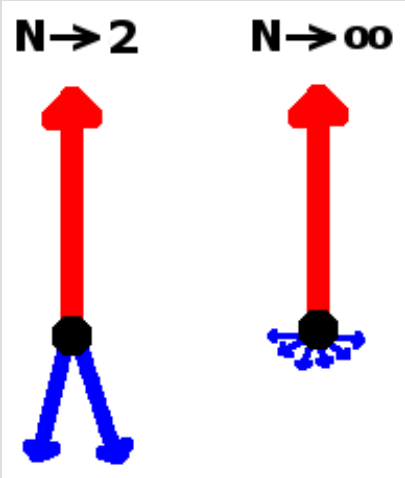
Good agreement between SPS experiments

Two-particle Δϕ Correlations
Other Systems



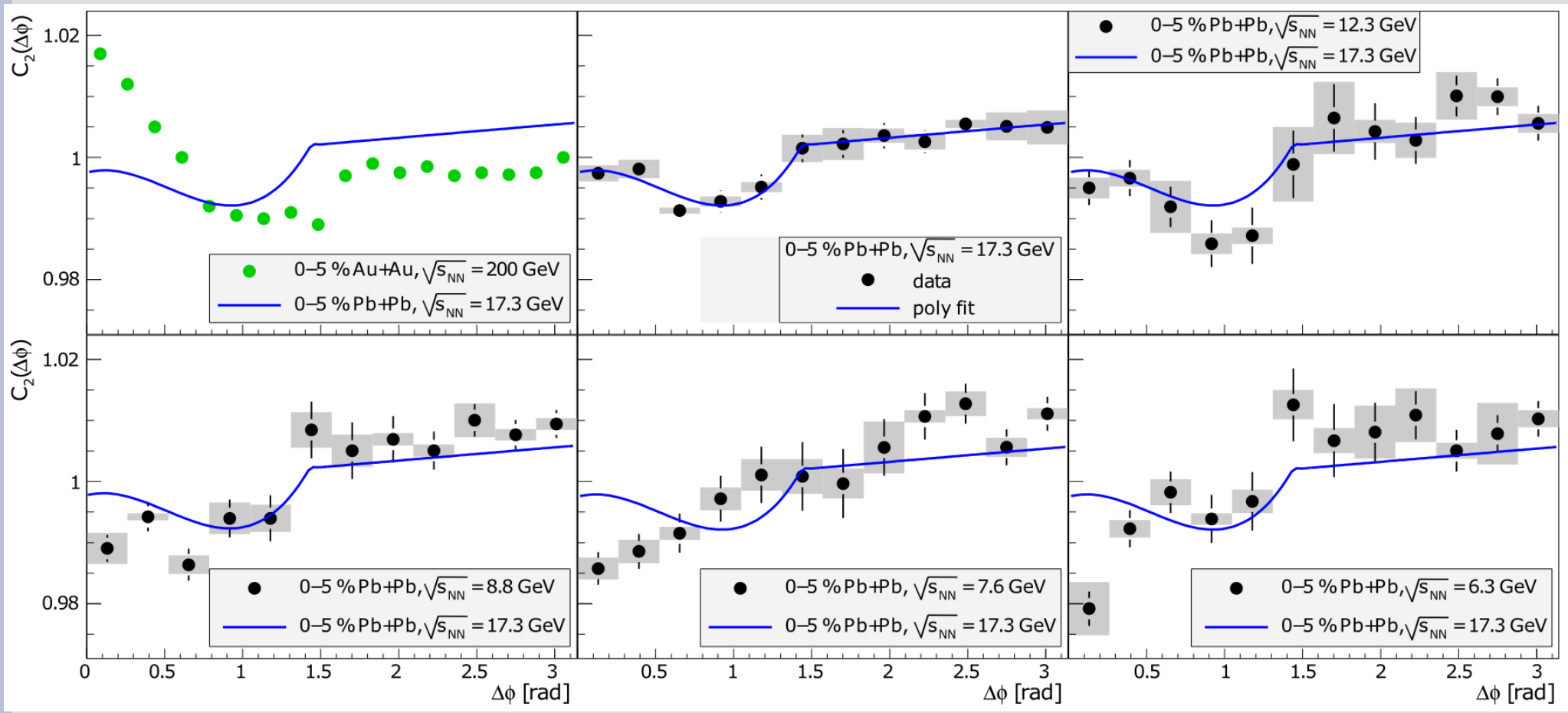


- Correlation stronger in smaller systems
- Away side: steeper peak in smaller systems
- Global momentum conservation?



Two-particle Δϕ Correlations

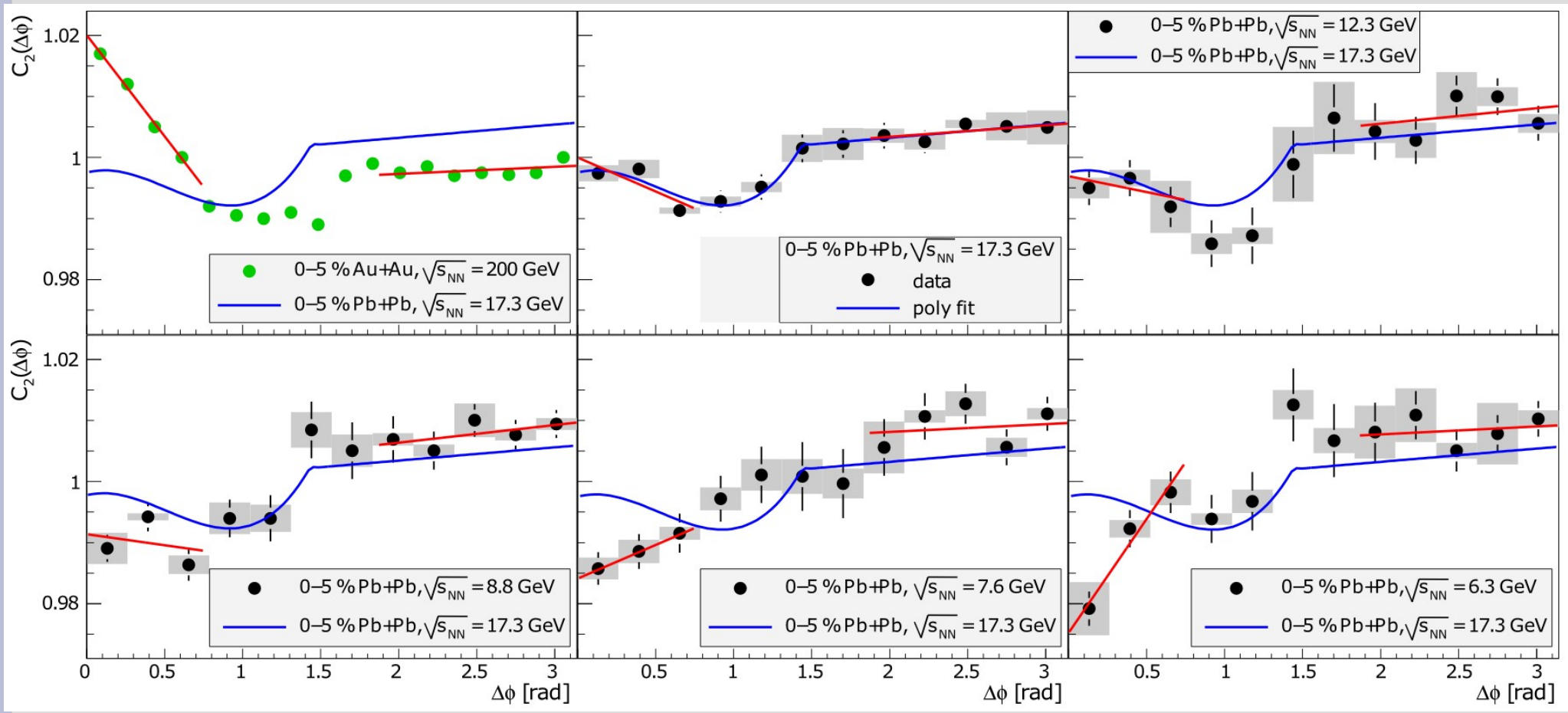
Energy scan of central collisions



- *PHENIX, Phys.Rev.Lett.97:052301,2006*

Two-particle Δϕ Correlations

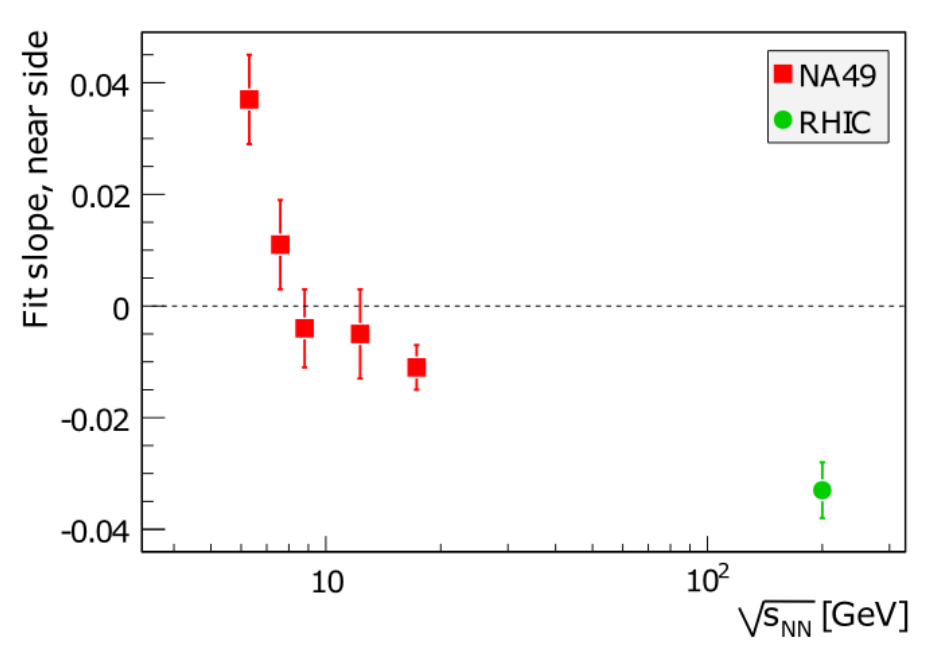
Energy scan of central collisions

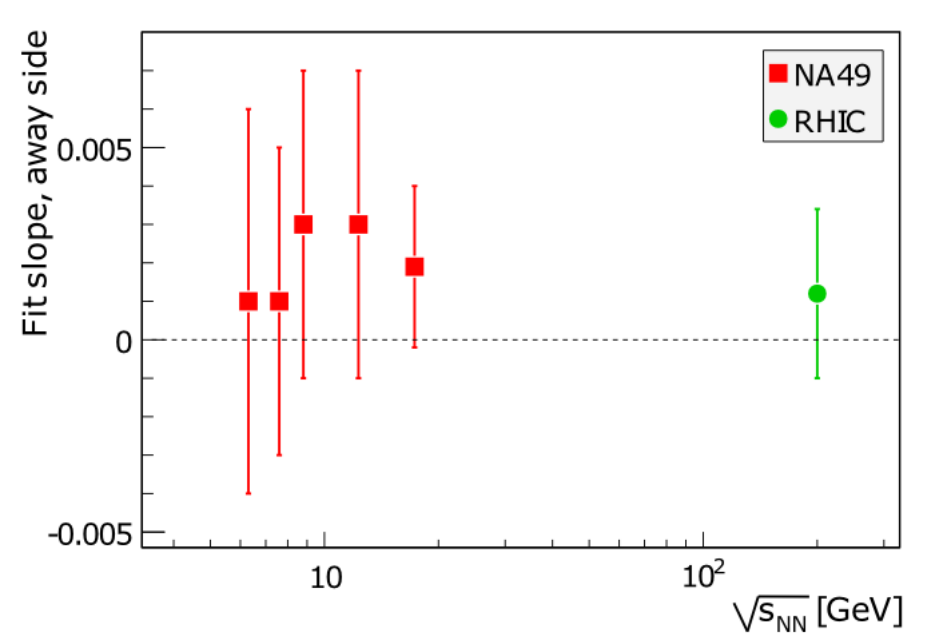


- *PHENIX, Phys.Rev.Lett.97:052301,2006*

Two-particle Δϕ Correlations

Energy scan of central collisions

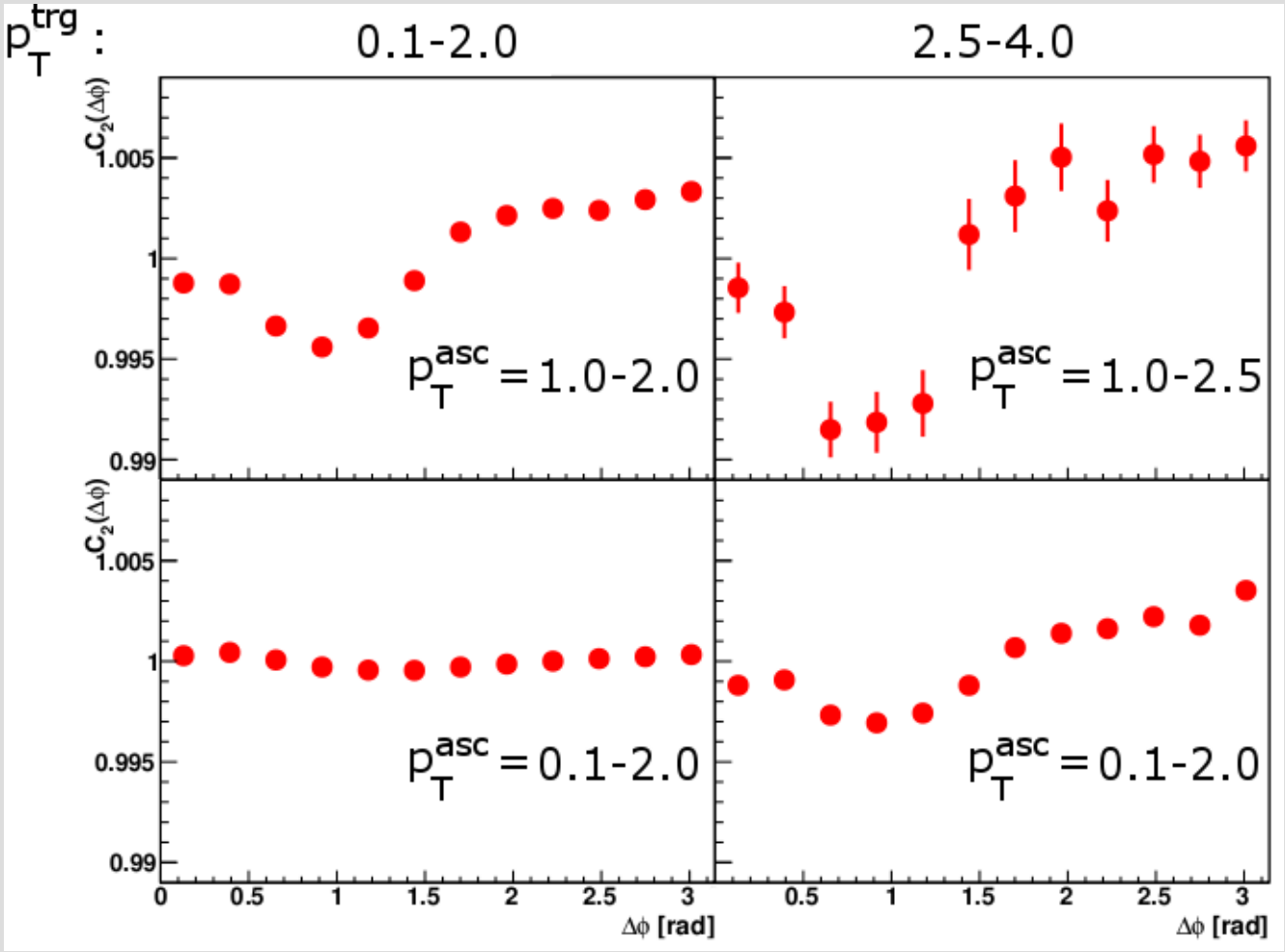




- Near side: slope changes with decreasing energy
  - sign change near 40A GeV, where onset of deconfinement is seen
    - *NA49, Phys.Rev.C77:024903,2008*
  - coincidence?
- Away side: weak or no energy dependence!
  - global momentum conservation?

Two-particle Δϕ Correlations
p_T scan, Pb+Pb at 158*A* GeV

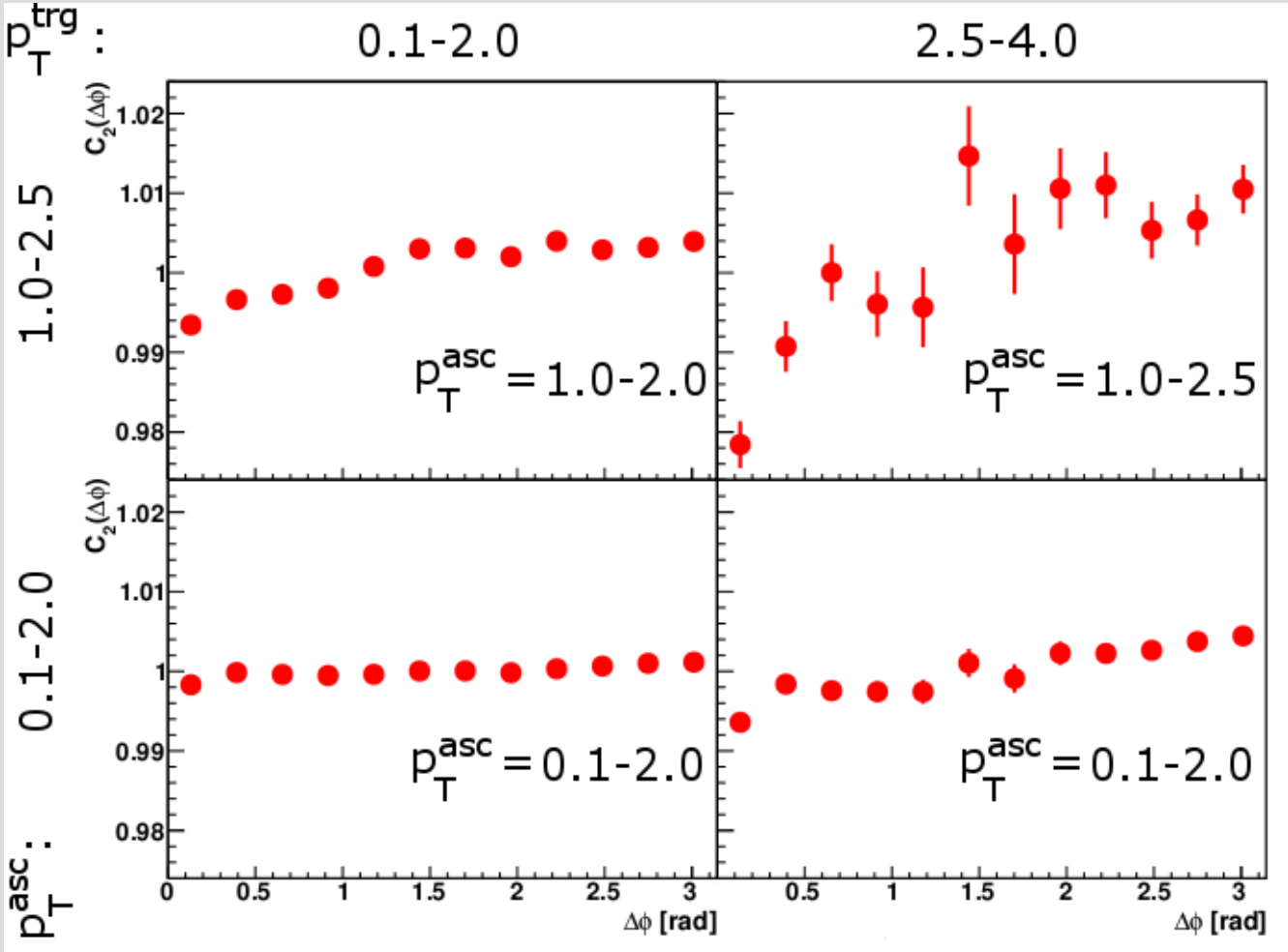
- No qualitative changes with trigger, associate p_T ranges
- Peak on the near side



Reminder: in each pair, $p_T^{asc} < p_T^{trg}$

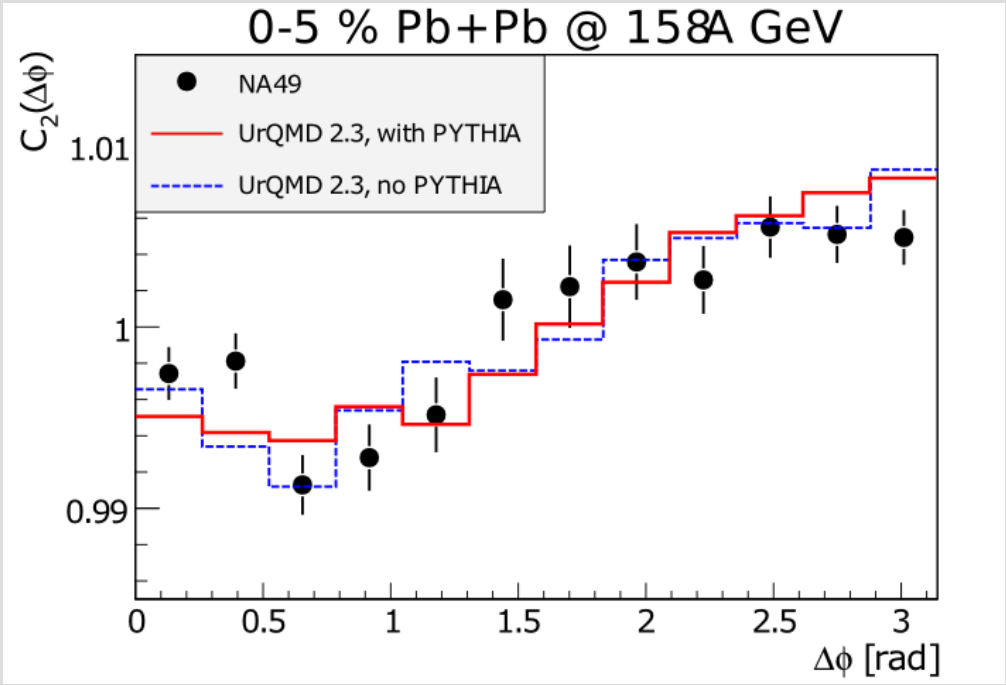
Two-particle Δϕ Correlations
p_T scan, Pb+Pb at 20*A* GeV

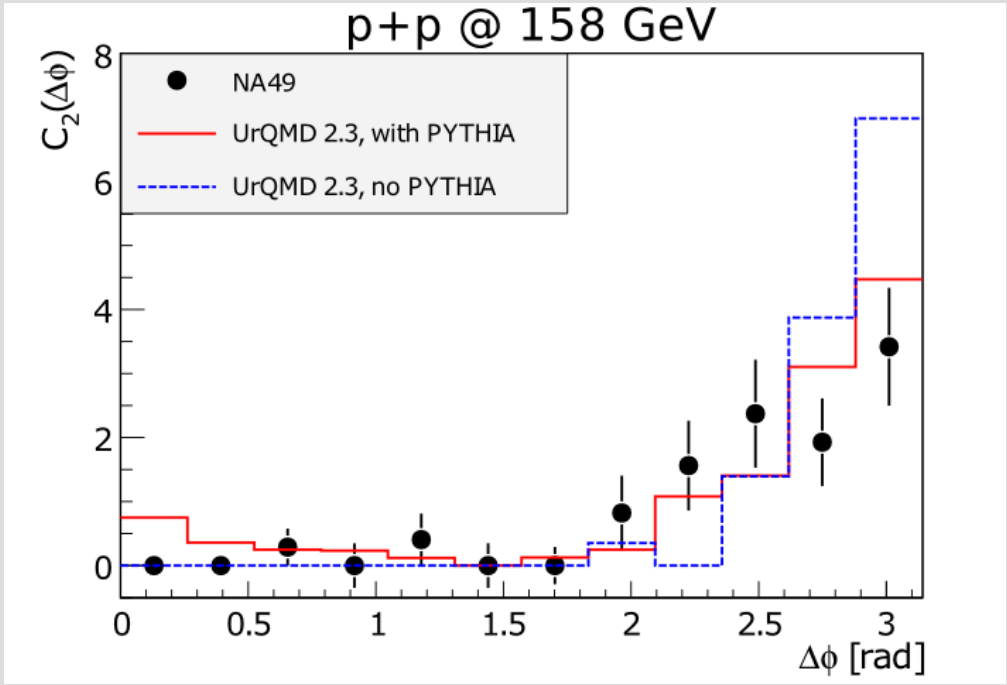
- No qualitative changes with trigger, associate p_T ranges
- Depletion on the near side



Reminder: in each pair, $p_T^{asc} < p_T^{trg}$

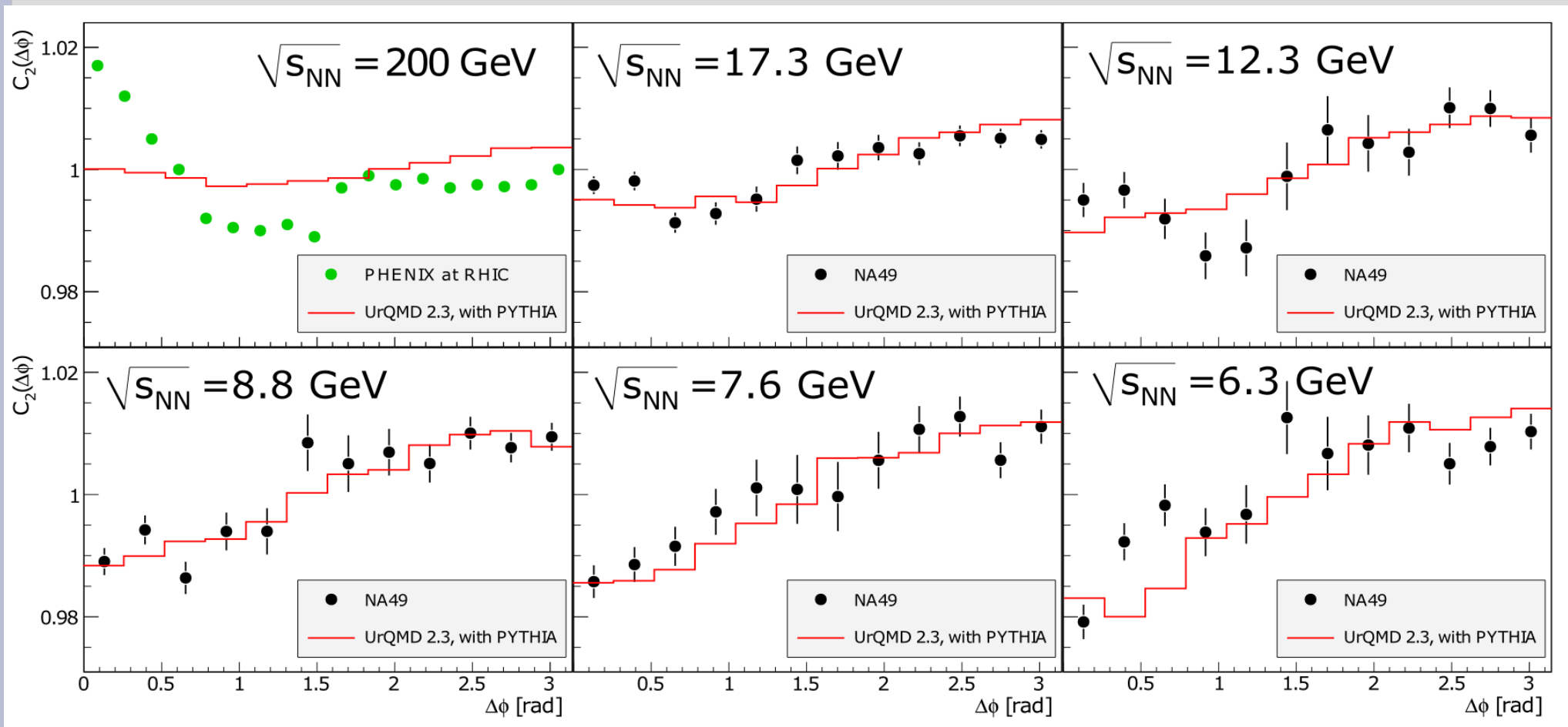
Two-particle Δϕ Correlations
Comparison with UrQMD



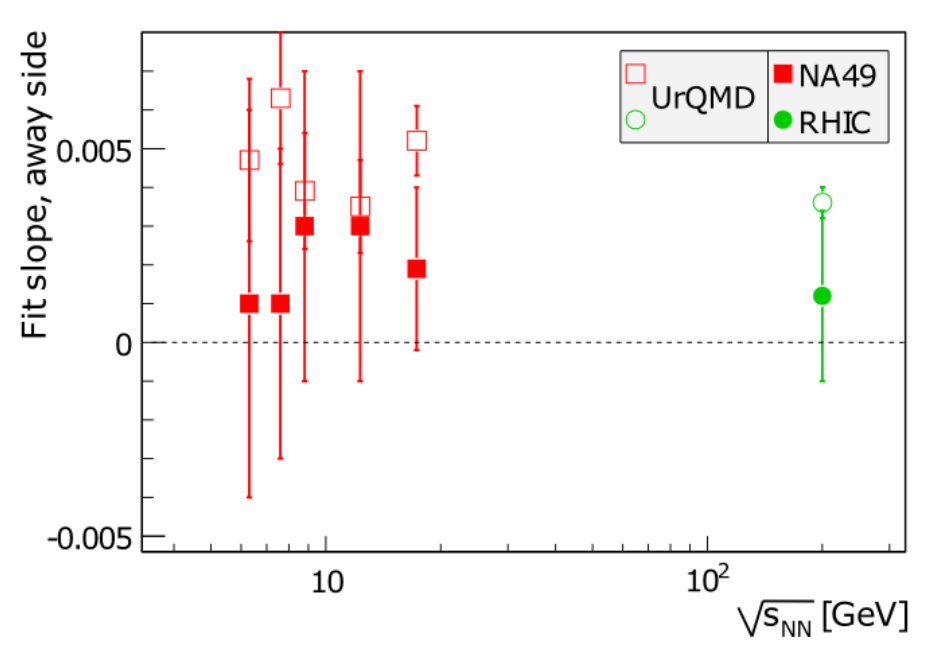


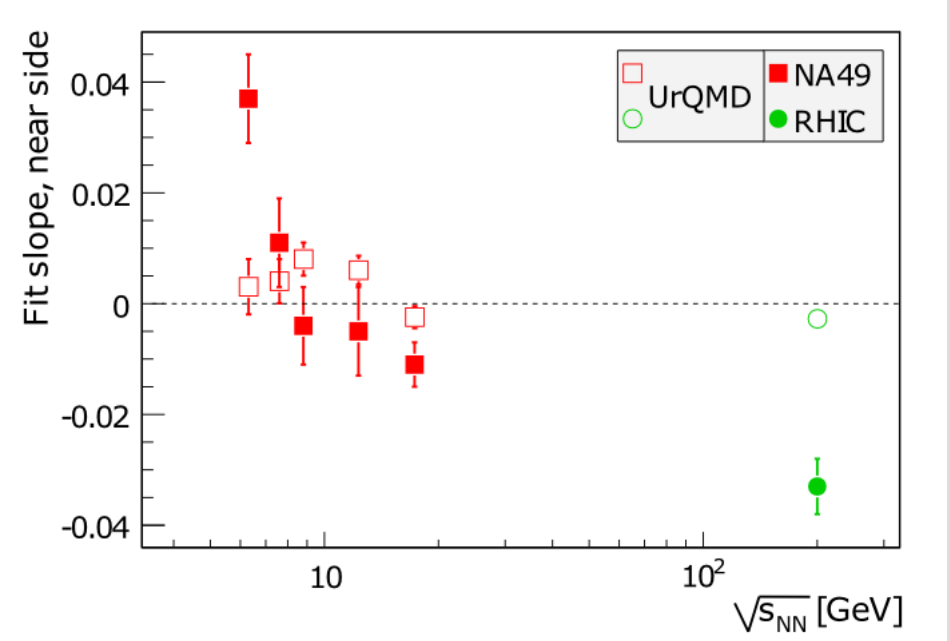
- Good agreement between model and data
- Hard-scattering contribution minor

Two-particle Δϕ Correlations
Comparison with UrQMD



Two-particle Δϕ Correlations
Comparison with UrQMD

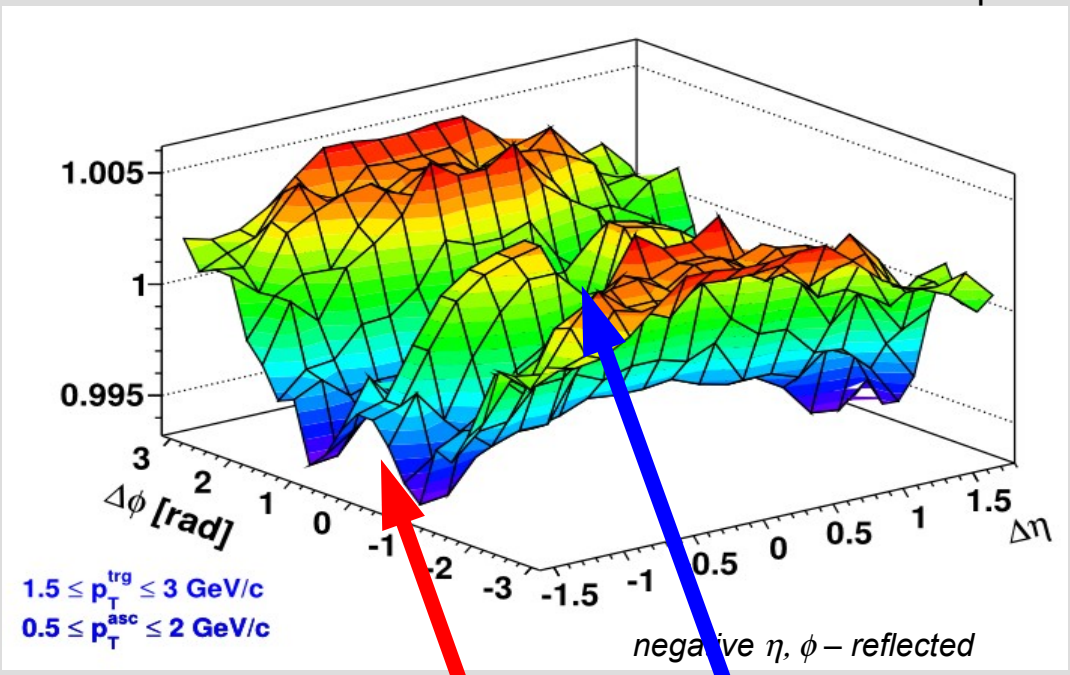




- Away-side trend consistent with experiment
- Discrepancy on the near side

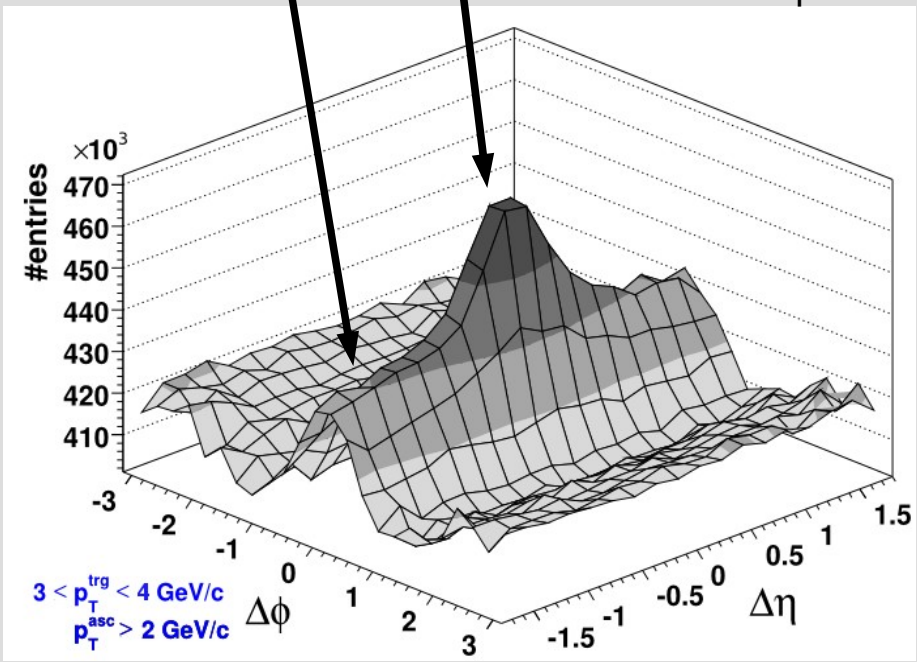
Two-particle (Δη,Δφ) Correlations

central Pb+Pb at 17.3 GeV/pair



STAR: Ridge and jet clearly visible

central Au+Au at 200 GeV/pair



NA49: Ridge? Dip

J. Putschke, J.Phys.G34:S679-S683,2007

Summary

- Energy, system-size dependence of two-particle azimuthal correlations measured by NA49 at SPS

- Two-particle azimuthal correlations
  - Centrality dependence, Pb+Pb at 158*A* GeV:
    - flattened away side in central collisions
    - similar to RHIC results
  - Charge dependence, central Pb+Pb at 158*A* GeV:
    - near side amplitude changes of unlike- vs. like-sign pairs suggest charge conservation
  - Pb+Pb at 158*A* GeV: agreement with CERES

Summary

- Two-particle azimuthal correlations
  - Energy and system-size scans:
    - away side strongly dependent on system size, weakly on energy
      - global momentum conservation
    - near side amplitude dropping with decreasing energy
      - peak-depletion transition *around 40*A *GeV* – onset of deconfinement?
      - shape stable with trigger, associate p_T-range changes
- Two-particle ($\Delta\eta$,$\Delta\phi$) correlations
  - Ridge seems to be present in Pb+Pb at 158*A* GeV
  - Dip near (0,0)

Summary

- UrQMD comparison
  - 158*A* GeV: good agreement with data for both p+p and Pb+Pb
    - hard contribution minor
  - Pb+Pb energy scan:
    - good away-side agreement
    - near side: discrepancy for both correlation strength and its trend

THANK YOU

BACKUP SLIDES

Event and Track Cuts

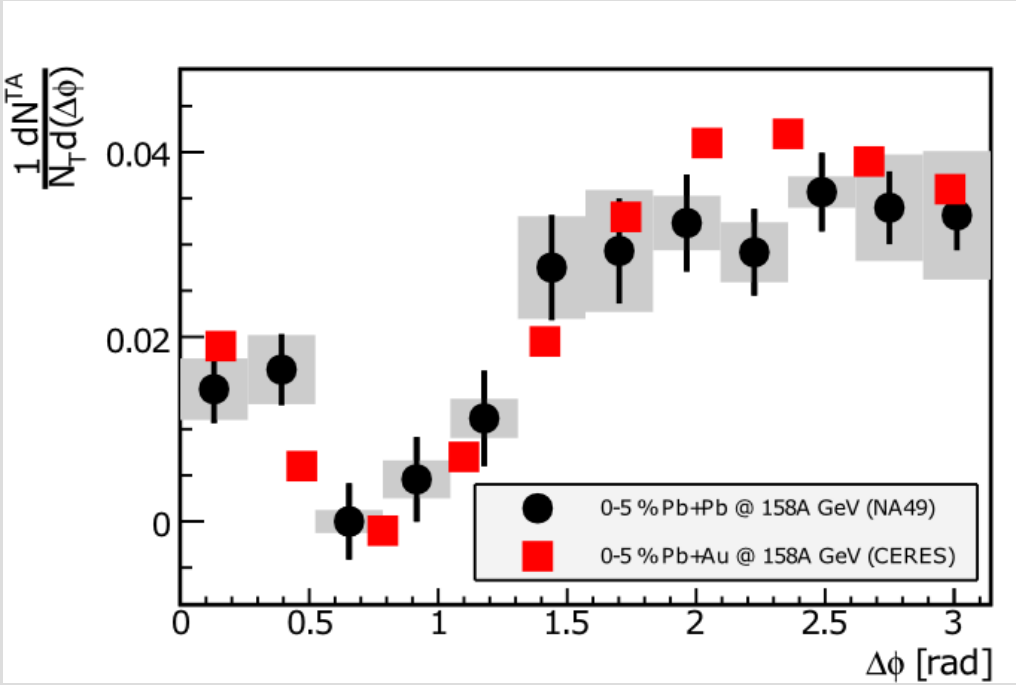
- Mixing: 50 last events
- Centrality bins: 0-5 %, 5-10 %, 10-20 %
- Reconstructed position of the primary vertex
- Track impact parameter (b)
- TPC N_{points}/N_{max} ratio
- TPC N_{max} for $N_{point} = 0$
- $2.5 \leq p_T^{trg} \leq 4.0$ GeV/c
- $1.0 \leq p_T^{asc} \leq 2.5$ GeV/c

Systematic Errors

- Pertinent sources:
  - secondary tracks classified as primary
  - split tracks
  - estimated via cut variation:
    - track impact parameter
    - real-to-potential TPC point ratio
- All sources added in quadrature
- Found negligible: two-track resolution, event-mixing classes, number-of-points cut, broken-track cut

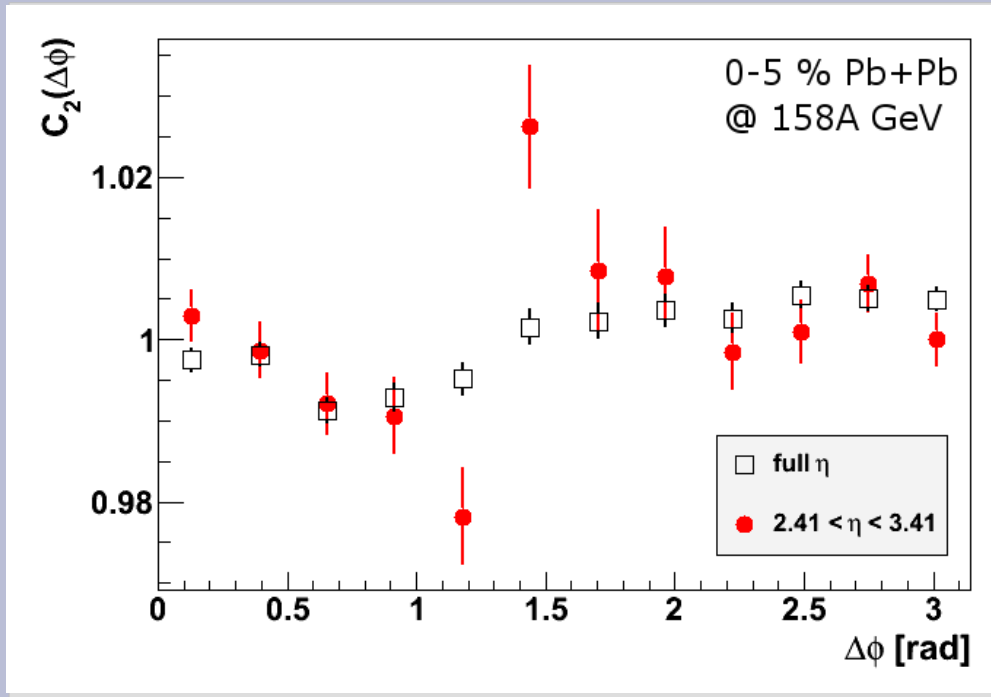
Two-particle Δϕ Correlations
Pb+Pb at 158*A* GeV

Comparison with CERES
– per-trigger yield

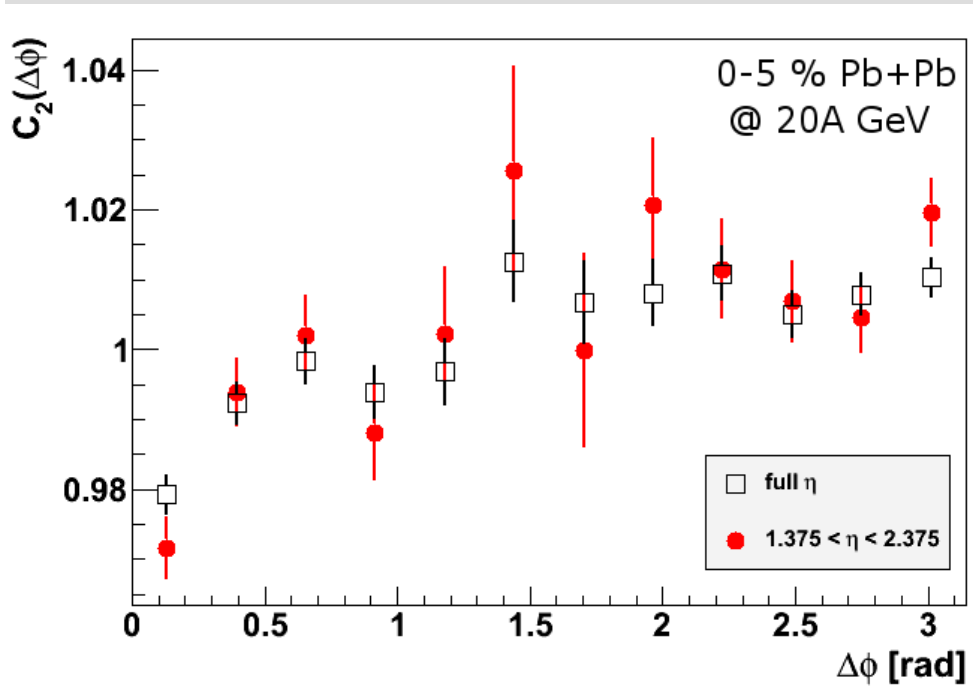


S. Kniege for CERES, talk at ISMD 2007

Full vs. mid-rapidity

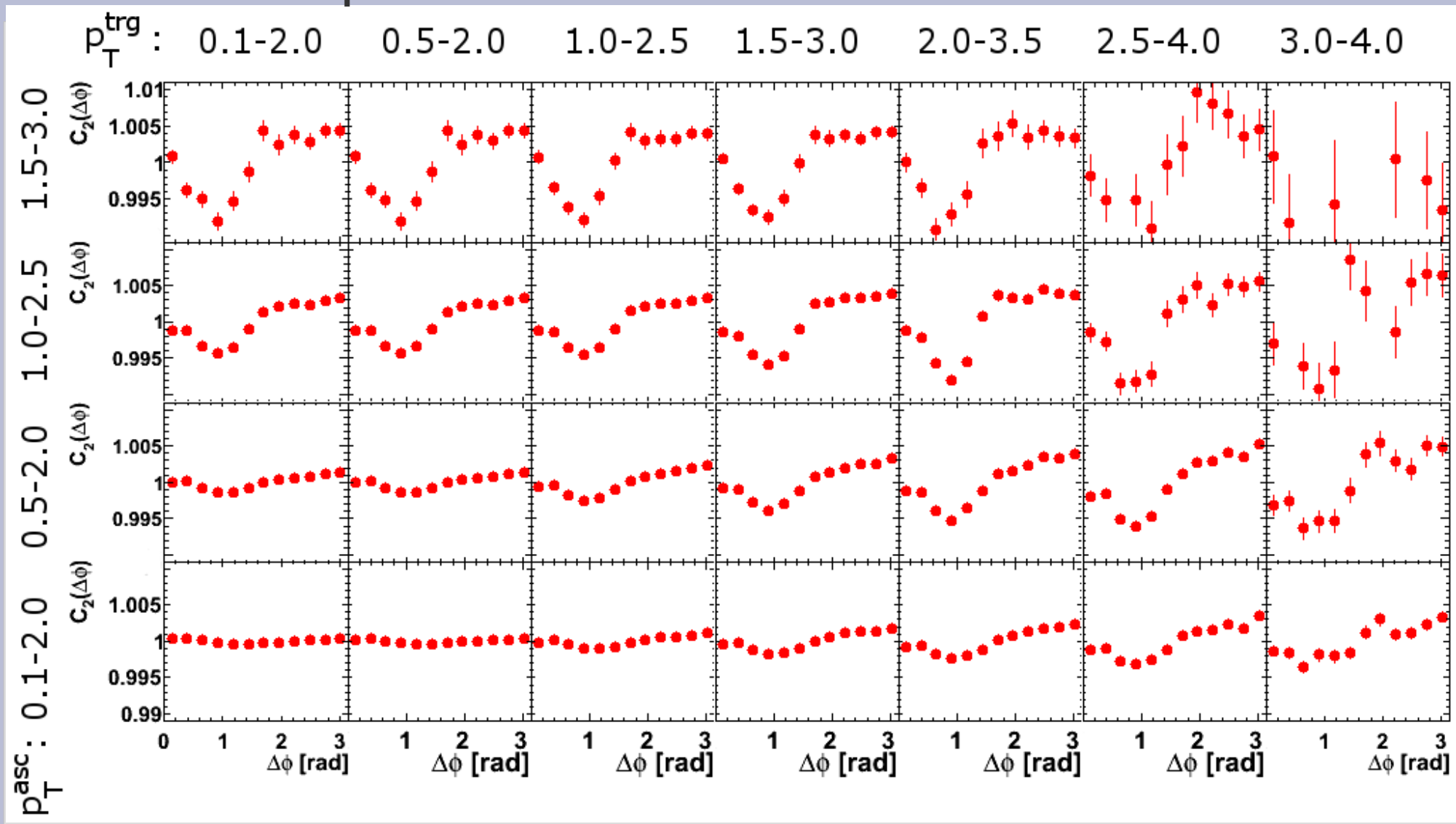


N_{pairs}	158*A*	20*A*
full η	3973314	916425
cut η	673904	304737



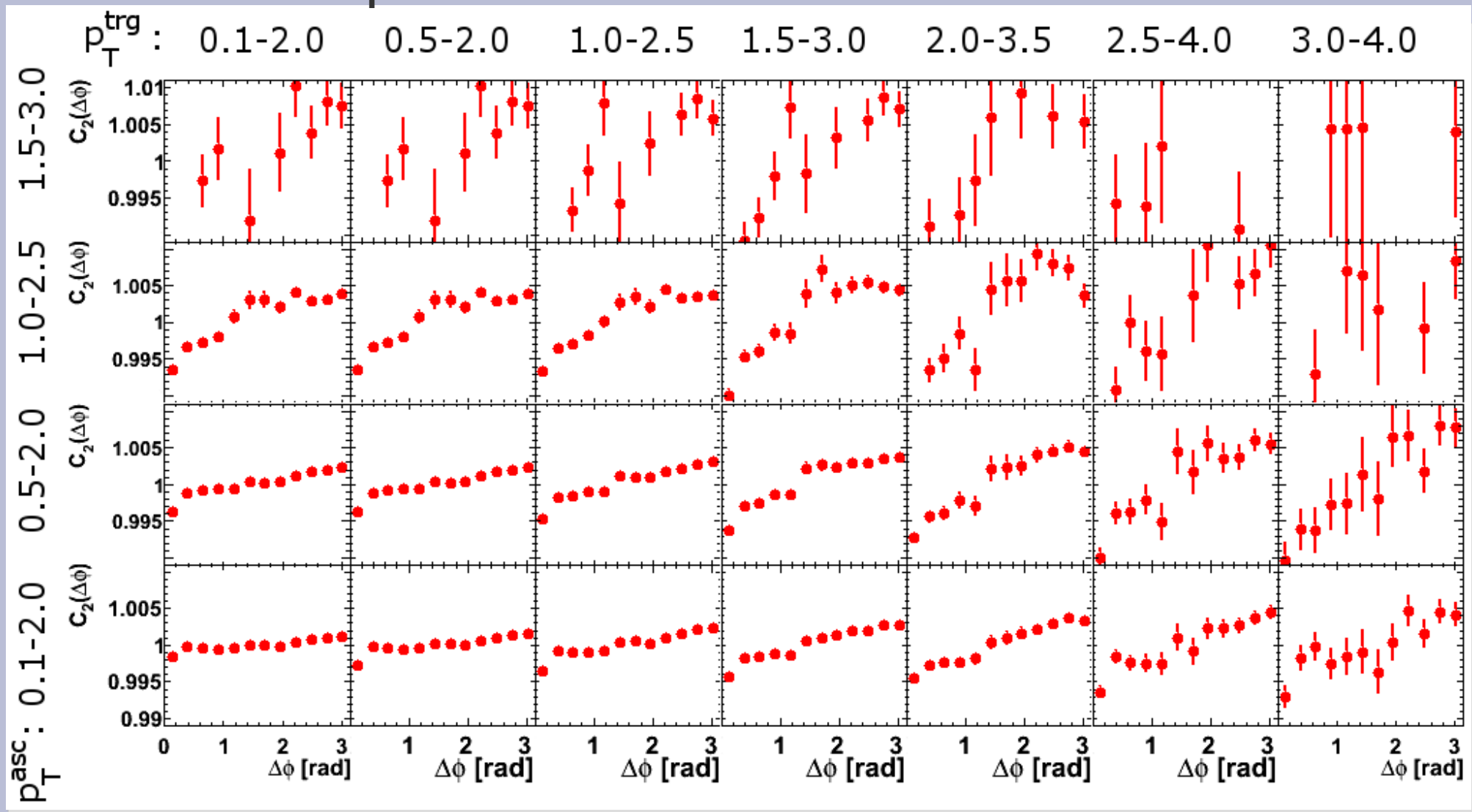
Two-particle $\Delta\phi$ Correlations

p_T scan, Pb+Pb at 158*A* GeV



Two-particle $\Delta\phi$ Correlations

p_T scan, Pb+Pb at 20*A* GeV



Two-particle (Δη,Δφ) Correlations